

AN INFRARED MULTIWAVELENGTH LIDAR FOR COMPOSITIONAL MAPPING. P. G. Lucey¹, X. Sun², S. X. Li², K. Numata², E. Mazarico², G. A. Neumann², J. B. Abshire², and D. E. Smith³, ¹Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, 1680 East-West Road, Honolulu, HI 96822, USA (lucey@higp.hawaii.edu), ²NASA Goddard Space Flight Center, Greenbelt MD 20771 USA, ³Massachusetts Institute of Technology, Cambridge MA, USA

Introduction: Infrared spectral remote sensing has been a mainstay of planetary exploration with its combination of high spatial resolution and rich compositional information content. To date these data have been obtained passively, using spectrometers that exploit solar reflected or thermally emitted photons as the light source. While passive spectral imaging is an exceedingly powerful technique, it is not without its shortcomings. Chief among them are the limitations imposed by the temperature of the source or the intensity of the sun, and the need to photometrically normalize the data which can lead to artifacts or poorly known uncertainties.

A lidar carries its own light source and overcomes these limitations. For example, while limited imaging is available in the permanently shadowed regions of the Moon using light reflected off nearby illuminated surfaces [1,2] quantitative single wavelength reflectance data in regions of permanent shadow are available from the LOLA and MLA laser altimeters [3,4]. These single band laser reflectance measurements can be compared across the entire data

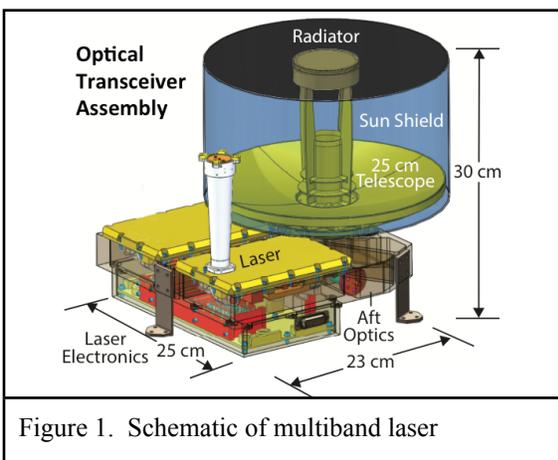


Figure 1. Schematic of multiband laser

sets without the need for any photometric normalization that might, for example, obscure latitude dependent spectral trends. For example, data from LOLA reveals that permanently shadowed regions are brighter than those that receive some illumination, but scattered light imaging using LROC has been unable to detect these subtle differences.

While LOLA and MLA (and MOLA) measurements are single band, obtaining multiple

wavelength measurements is now possible (e.g. [5]). Recently we have been developing laser and detector technology to emphasize the 3 micron region of the spectrum most sensitive to water and other volatile species, including methane and simple organics, and to collect data not just in a single band, but at up to 7 wavelengths.

LIDAR Development. Any laser remote sensing system requires both a laser and a receiver and at Goddard we have been developing both for operation in the 3 micron region.

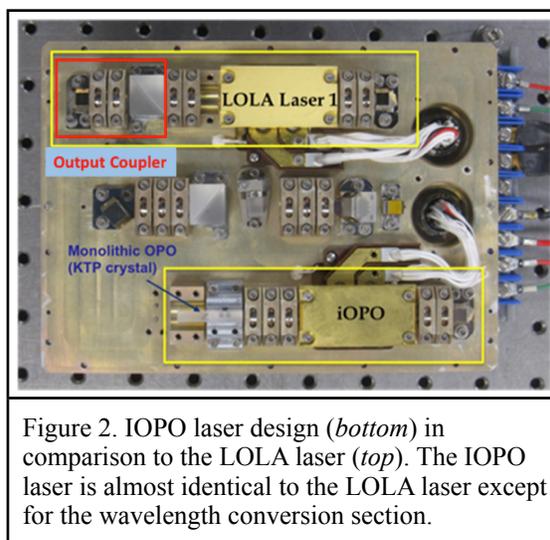


Figure 2. IOPO laser design (bottom) in comparison to the LOLA laser (top). The IOPO laser is almost identical to the LOLA laser except for the wavelength conversion section.

Lasers. We have been developing two technologies in parallel, each of which converts a 1064 nm laser to infrared output. The two related technologies are Optical Parametric Amplifiers (OPA) [6] and Intracavity Optical Parametric Oscillators (IOPO) [7]. In both cases a LOLA-like pulsed laser provides the principal input energy to a non-linear crystal that accomplishes the down-conversion of the light to infrared wavelengths. The OPA system contains more subsystems, requiring near-IR seed lasers to select the 3 micron region wavelengths, but only requires a single pump, while the IOPO system is simpler and more compact, but imposes more constraints on the choice of the output wavelengths and requires a LOLA-like pump laser for each pair of near-IR and 3 micron region outputs. The TRL of the IOPO approach benefits from the flight heritage of the LOLA laser.



Figure 3. Integrated detector-cooler assembly (IDCA) from the InVEST program for an in-space demonstration on a 3U CubeSat. The IDCA is 8x8x20 cm in size and consumes 7-10 W electrical power.

Detectors. For several years we have been developing infrared lidar detectors based on HgCdTe avalanche photodiodes under the NASA ESTO (Earth Science Technology Office) IIP (Instrument Incubator Program) [8]. This effort has led to small (up to 2x8 and 4x4) arrays of pixels well suited to the spectral detection task. These detectors are sensitive from 0.4 to 4.5 microns and are much more sensitive than the Si APD detectors used in LOLA. These detectors have been successfully used in airborne methane and CO₂ lidar measurement campaigns in the last few years. We are currently qualifying a version of these detectors for the InVEST program for a CubeSat in-space demonstration.

Unique Features. The multiple wavelength lidar system is immune to solar and thermally emitted radiation from the target surface because of the extremely short pulse durations (a few nanoseconds). During the brief laser pulse, the laser is much more intense than the natural sources of radiation. Therefore, day and night measurements can be directly compared.

Proof of Concept: We have conducted experiments demonstrating the technique, and to measuring very small amounts of surface frost condensed from water vapor onto cryogenically cooled lunar simulant. These measurements were supported by the NASA GSFC IRAD program. For these experiments we modified an optical parametric amplifier (OPA) laser that was originally developed for an airborne methane lidar [6]. We added more diode

seed lasers to obtain additional wavelengths. This allowed the OPA output to span several wavelengths across the 3 μm water ice absorption band. Some preliminary results are shown in Figure 4.

Applications: For the Moon, reflectance measurements near 3 μm can definitively answer the question of whether water is mobile by comparing

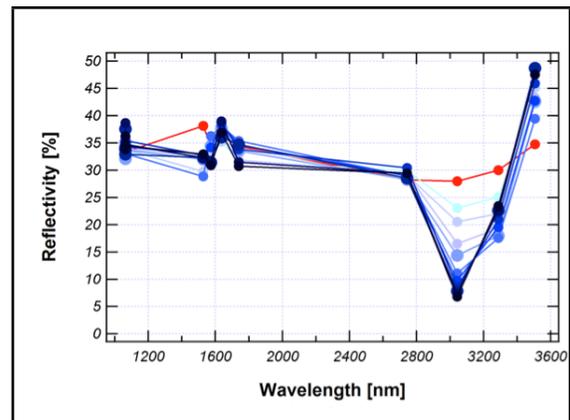


Figure 4. Initial results from laser reflectance measurements made to lunar simulant at ~ 160 K. The different colors indicate reflectance measured to the cold surface exposed to increasing numbers of water vapor injections, or "loads"

band depths during both day and night. At Io, the instrument can uniquely measure the reflectance of active lava lakes. For icy satellites and Trojans, the instrument can provide high quality characterization of volatile migration by comparing day and night reflectances and bands. For dense comet comae, lidar can measure in three dimensions the particle sizes and the ratio of ice to non-icy species, including organics and salts.

References: [1] Speyerer, E. J., and M. S. Robinson (2011), Analysis of highly illuminated zones near the lunar south pole, *Lunar Planet. Sci.*, **42**, Abstract 2540., [2] Chabot, Nancy L., et al. *Geophysical Research Letters* 39.9 (2012). [3] Lucey, P.G. et al. (2014), *J. Geophys. Res. Planets* 119, 1665-1679. [4] Zuber, M. T. et al. (2012), *Nature*, 486(7403), 378-81. [5] Cohen BA, Hayne PO, Paige DA, Greenhagen BT. Annu. Meet. Lunar Explor. Anal. Group. 2014 Jul 21:3031. [6] Numata, K. et al. (2012), *Journal of Applied Remote Sensing* 6(1), 063561. [7] Oshman, M. K. and S. E. Harris (1968), *IEEE J. Quantum Electron.* QE-4, 491-502. [8] Sun, X., J. B. Abshire, and J. Beck (2014), *Proc. SPIE* 9114.